LCA Case Studies

Life Cycle Assessment for the Implementation of Emission Control Measures for the Freight Traffic with Heavy Duty Vehicles in Germany

Phase 2: Life Cycle Impact Assessment *

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Abstract. Under consideration of the overall Life Cycle Inventory Analysis (LCI) results generated in the first step of this study and based on the February 1999 edition of ISO/DIS 14042 the Life Cycle Impact Assessment (LCIA) for the introduction of various emission control measures for freight traffic heavy duty vehicles in Germany was determined. For the examination of the several mandatory elements 11 impact categories related to the freight traffic and the LCI results were focussed, the LCI results were designed to these impact categories and with characterization factors of the 11 selected and recognized characterisation models the categories indicator endpoints were quantified. The optional elements for normalization and weighting were added to the analysis. Two reference values are used for normalizing the category indicator results. For the weighting step 8 recognized evaluation methods were selected with the aim to aggregate the LCI results to an overall value. The results enable plausible conclusions with regard to the ecological advantages and disadvantages of the use of each analysed emission control technology for heavy duty diesel vehicles. As no perfectly clear ranking can be distinguished for evaluation of the generated results and no correlation can be established to the economical effects of the corresponding measurements, it is necessary to complete the currently existing recommendation from the ISO/DIS-Standards with further parameters.

Keywords: Diesel engines; diesel fuel-based measures; engine-based measures; freight traffic; heavy duty vehicles; life cycle impact assessment; nitrogen oxides; particulate trap; SCR catalysts; urea selective catalytic reduction process

Introduction

This analysis represents the second phase of the LCA as per [1]. It is a continuation from the life cycle inventory (LCI) results published in [2] for the introduction of various measures for reducing emissions of heavy-duty vehicles used for freight traffic in Germany. This Life Cycle Impact Assessment (LCIA) is based on the February 1999 edition of ISO/DIS 14042 (cf. [3]). For characterization and weighting of the LCI results assigned to the impact categories, a series of various methods was applied to limit the influences of conceptual deficiencies and gaps in the factors for characterization and weighting on the result of the LCIA.

1 Mandatory Elements

1.1 Classification and characterization

The LCI results assigned to the impact categories are detailed in **Appendix 1**. The following methods were applied for characterizing the category indicators:

- Use of energy resources: Model of cumulative energy demand, cf. [4].
- Use of material resources: Model of the reserve-to-use ratio, cf. [5].
- Use of water resources: Summary of LCI results as g overall water consumption.
- Human toxicity: CLM Provisional, cf. [5].
- Anthropogenic greenhouse effect (global warming): GWP factors from Intergovernmental Panel on Climate Change for reference time of 100 years (status 1994), cf. [5].
- Acidification of water and soil: Method of availability of H^+ protons from emitted pollutants in affected environmental medium, maximum scenario g SO_2 equivalent/g pollutant, cf. [5].
- Eutrophication: Method of availability of nutrients, maximum scenario g PO_4 equivalent/g pollutant, cf. [5].
- Generation of photooxidants (summer smog): Results of investigations in [6] for analysis of selected emissions from diesel engines as a function of fuel composition regarding specific reactivity (SR) of diesel exhaust gases and the resulting scale of 'maximum incremental reactivity' (MIR) by W.P.L. Carter accounted for in the California 'Low-Emissions Vehicles and Clean Fuel' Law, cf. [7, p. 19].
- Ecotoxicity: Method of toxicity equivalents, cf. [7].
- Radiation: Units of radioactivity Bq and dose rate as effective equivalent dose for exposure of persons in nuclear power plant operation man-Sieverts per year based

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Table 1: Summary of the results for the mandatory elements of the LCIA for the studied scenarios (SP: abbreviation for sensitivity test)

Category endpoints	EU3M, 2010	V_1, 2010	V_2, 2010	V_2, SP, 2010	V_3, 2010	V_3, SP, 2010	V_4, 2010
1. Resources							
Energy consumption in kWh	-3.39E+10	-5.39E+09	6.13E+10	6.13E+10	5.70E+10	5.70E+10	-1.01E+10
Material consumption	-7.15E+07	2.41E+05	1.43E+08	1.43E+08	1.29E+08	1.29E+08	-2.13E+07
2. Water consumption in g	-1.88E+13	5.62E+10	3.75E+13	3.75E+13	3.38E+13	3.38E+13	-5.61E+12
3. Land use in ELU	-3.85E+04	-4.70E+04	2.97E+04	2.97E+04	4.02E+04	4.02E+04	-1.15E+04
4. Human toxicity in g body weight	8.79E+06	9.64E+07	3.52E+08	3.52E+08	2.11E+08	2.11E+08	2.12E+08
5. Global warming in g CO_2-eq	-9.03E+12	-3.36E+11	1.75E+13	1.75E+13	1.59E+13	1.59E+13	-2.69E+12
6. Stratospheric ozone depletion	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.
7. Acidification in g SO_2-eq	3.99E+11	7.67E+11	7.96E+11	6.76E+11	2.45E+11	2.09E+11	1.33E+11
8. Eutrophication in g PO_4-eq	-2.56E+06	-6.08E+05	4.47E+06	4.47E+06	4.22E+06	4.22E+06	-7.64E+05
9. Summer smog in g ozone	9.77E+10	1.23E+12	1.27E+12	1.08E+12	7.16E+11	6.26E+11	6.06E+11
10. Ecotoxicity in t DBM	-1.13E+09	4.95E+08	2.59E+09	2.59E+09	2.21E+09	2.21E+09	2.80E+09
11.1 Radiation in Bq	-2.88E+11	0.00E+00	5.74E+11	5.74E+11	5.18E+11	5.18E+11	-8.60E+10
11.2 Radiation in man-Sievert/a	-7.23E-03	0.00E+00	1.44E-02	1.44E-02	1.30E-02	1.30E-02	-2.16E-03
12. Noise	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.
13. Waste in ERP	-2.41E+09	-1.83E+08	4.60E+09	4.60E+09	4.21E+09	4.21E+09	-7.18E+08

on tissue weighting factors for radiation sensitivity of the various organs of the human body, cf. [8].

- Waste: Method of ecoscarcity, cf. [9].

The applied characterization factors are detailed in Appendix 1.

1.2 Results of mandatory elements

Table 1 shows a summary of the final results of the mandatory elements for the LCIA. The influences of the individual LCI results on the final results of the impact categories are detailed in Appendix 1. The significance of these influences for LCA outcome is discussed in the third phase of the LCA, cf. [16].

2 Optional Elements

2.1 Normalization

The category indicator results are calculated relative to one (or more) selected reference value(s) to enable better understanding of the magnitude of the corresponding category indicator results for the scenarios under study. The following reference values are therefore used in this study for normalizing the category indicator results:

1. Category indicator results from 1995 reference conditions.
2. Traveled distance in km with measure.

The results are presented with **positive** sign for a reduction in load on the environment and with **negative** sign for loading of the environment.

Normalization of the category indicator results for the individual measures is based on the category indicator results for the reference year 1995 (Table 2) and expresses the fraction of reduction or increase in the load on the environment which can be achieved by implementation of a measure over the entire distance traveled (see [2]) relative to the starting year of the investigation. It enables quantification in percent of the entire attainable reduction or increase in the load on the environment with a specific strategy of measures relative to the actual status (Table 2). The category indicator results are also

Table 2: Standardization of category indicator results for measures to reduce emission based on the findings for the reference year 1995

Standardization	EU3M, 2010	V_1, 2010	V_2, 2010	V_2, SP, 2010	V_3, 2010	V_3, SP, 2010	V_4, 2010
1. Resource consumption							
Energy consumption	-32%	-5%	58%	58%	54%	54%	-10%
Material consumption	-32%	0%	64%	64%	58%	58%	-10%
2. Water consumption	-32%	0%	64%	64%	58%	58%	-10%
3. Land use	-32%	-39%	25%	25%	34%	34%	-10%
4. Human toxicity	3%	35%	128%	128%	76%	76%	77%
5. Global warming	-32%	-1%	62%	62%	57%	57%	-10%
6. Stratospheric ozone depletion	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.
7. Acidification	166%	320%	332%	282%	102%	87%	56%
8. Eutrophication	-32%	-8%	56%	56%	53%	53%	-10%
9. summer smog	20%	248%	256%	218%	144%	126%	122%
10. Ecotoxicity	-35%	15%	81%	81%	69%	69%	87%
11.1 Radiation	-32%	0%	64%	64%	58%	58%	-10%
11.2 Radiation, AKW	-32%	0%	64%	64%	58%	58%	-10%
12. Noise	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.
13. Waste	0%	0%	0%	0%	0%	0%	0%

Table 3: Standardization of the impact indicator results for measures to reduce the emission based on the travel performance with the measure concerned

Standardization	EU3M, 2010	V_1, 2010	V_2, 2010	V_2, SP, 2010	V_3, 2010	V_3, SP, 2010	V_4, 2010
1. Resources							
Energy consumption in kWh/km	-1.83E-01	-2.90E-02	3.30E-01	3.30E-01	5.02E-01	5.02E-01	-8.92E-02
Material consumption in km^{-1}	-3.85E-04	1.30E-06	7.69E-04	7.69E-04	1.13E-03	1.13E-03	-1.88E-04
2. Water consumption in g/km	-1.01E+02	3.03E-01	2.02E+02	2.02E+02	2.98E+02	2.98E+02	-4.94E+01
3. Land use in ELU/km	-2.08E-07	-2.53E-07	1.60E-07	1.60E-07	3.54E-07	3.54E-07	-1.01E-07
4. Human toxicity in g body weight/km	4.74E-05	5.20E-04	1.90E-03	1.90E-03	1.85E-03	1.85E-03	1.86E-03
5. Global warming in g CO_2 eq/km	-4.87E+01	-1.81E+00	9.43E+01	9.43E+01	1.40E+02	1.40E+02	-2.37E+01
6. Stratospheric ozone depletion	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.
7. Acidification in g SO_2 eq/km	2.15E+00	4.14E+00	4.29E+00	3.65E+00	2.16E+00	1.84E+00	1.17E+00
8. Eutrophication in g PO_4 eq/km	-1.38E-05	-3.28E-06	2.41E-05	2.41E-05	3.72E-05	3.72E-05	-6.73E-06
9. Summer smog in g ozone/km	5.27E-01	6.63E+00	6.83E+00	5.83E+00	6.31E+00	5.52E+00	5.34E+00
10. Ecotoxicity in t DBM/km	-6.08E-03	2.67E-03	1.39E-02	1.39E-02	1.95E-02	1.95E-02	2.46E-02
11.1 Radiation [Bq/km]	-1.55E+00	0.00E+00	3.09E+00	3.09E+00	4.56E+00	4.56E+00	-7.58E-01
11.2 Radiation in man-Sievert/(a*km)	-3.90E-14	0.00E+00	7.76E-14	7.76E-14	1.14E-13	1.14E-13	-1.90E-14
12. Noise	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.
13. Waste in ERP/km	-1.30E-02	-9.85E-04	2.48E-02	2.48E-02	3.70E-02	3.70E-02	-6.32E-03

normalized relative to the overall distance traveled with the corresponding strategy of measures (Table 3), cf. [2]. This expresses the overall achievable reduction or increase in the load on the environment per measure kilometer traveled with a specific strategy of measures. This code thus enables more objective evaluation of the corresponding measure in a traffic system.

2.2 Weighting

As weighting of the effect indicator results can be particularly influenced by the value choices of individuals, it is preferred in this context to use a number of several quantitative and standard evaluation methods with the aim to aggregate the LCI results to an overall value (Table 4):

- Method of ecoscarcity with evaluation factors for Switzerland [9],
- Method of ecoscarcity with evaluation factors for Norway, cf. [5],
- Method of ecoscarcity with evaluation factors for Sweden, cf. [5],
- Tellus system, Tellus Institute, Boston, U.S.A., cf. [5],
- EPS system (Environmental Priority Strategies in product design), Swedish Environmental Research Institute IVL, cf. [5,10],
- Method of effect category, short time, cf. [5],
- Method of effect category, long time, cf. [5],
- Concept of Quality Target Relations, (known as the 'Mol method'), cf. [5] and [11, pp. 73 ff.].

Reference is made to [9], [12], [13], [5], [11] and [10] for an extensive overview of the applied methods.

Table 4: Results of weighting as environment relief units **(with positive prefix)** for the applied, quantitative weighting method

Weighting method	EU3M, 2010	V_1, 2010	V_2, 2010	V_2, SP, 2010	V_3, 2010	V_3, SP, 2010	V_4, 2010
Ecoscarcity, Switzerland in ERP [10^9]	22.194	46.619	49.122	41.892	16.609	14.258	8.509
Tellus U.S.A., in reduction of U.S. $ costs [10^6]	3.619	9.004	10.229	8.844	4.053	3.575	2.105
EPS, in reduction of ECU costs [10^6]	-785	226	1.827	1.788	1.571	1.549	-100
Effect category, in reduction of short-term units [10^9]	1.664	4.392	5.067	4.382	2.085	1.844	909
Effect category, in reduction of long-term units [10^9]	747	4.116	5.339	4.692	2.796	2.524	1.161
CQR, in reduction of EPSU [10^9]	2.985	5.945	6.329	5.415	2.064	1.784	1.006
Ecoscarcity, Norway in ERP [10^9]	3.815	10.162	11.725	10.127	4.905	4.326	2.252
Ecoscarcity, Sweden in ERP [10^9]	1.352	5.064	5.933	5.094	2.802	2.441	1.593

Table 5: Qualitative assessment of the data quality (a: acquisition method, b: independence of data supplier, c: representativeness of sample, d: data age, e: geographical correlation, f: technological correlation and g: data age < 10 years with due consideration to the reference years for the quoted data in the applied sources)

Data	a[a]	b[b]	c[c]	d[d]	e[e]	f[f]
Hard coal mining	3	2	5 (unknown)	2 to 3[g]	1	1
Lignite coal mining	3	2	5 (unknown)	2 to 3[g]	1	1
Natural gas extraction and transport	3 to 4	2	5 (unknown)	1, 2 to 3[g]	2	1 and 3
Mineral oil extraction	3	2	5 (unknown)	1, 2 to 3[g]	2	3
Refinery process	2 and 3	1	5 (unknown)	1 to 2	2	2 to 3
Nuclear fuel cycle	2 and 3	1	5 (unknown)	1 and 2 to 3[g]	1	1 and 2
Energy conversion and transport (current from power stations in Germany)	2	1 and 2	5 (unknown)	1 to 2	1	1
HDV, status 1995, emissions	2	1	1	1 to 2	1	1
HDV, status 1995, traffic data	1 to 2	1	1	1 to 2	1	1
HDV, status 2000, 2005 and 2010, traffic data	3	1	5 (unknown)	1	1	1
Fuel side measures on HDV	1	1	1	1	1	1
Motor engine side measures on HDV	1	1	1 to 2	1	1	1
Exhaust gas side measures on HDV (SCR process)	1	1 to 2	1 to 2	1	1	1
PLC of SCR systems	1 to 2	2	2	1	1	1

3 Data Quality Analysis

The checklist in accordance with [5] is used for performing a qualitative analysis of the data quality. This checklist yields the following evaluation of the quality of the data records used (**Table 5**). This shows that the data exhibit very good quality for the range of heavy duty vehicles (emissions, traffic and primary measures) and the SCR systems (PLC and application in heavy duty vehicles). In contrast, the quality of the data for the upstream processes is somewhat lower but can still be classified as good. These data were obtained from an extensive research program with the participation of official and independent institutions, equipment suppliers and operators, and represent the current status (cf. [8,14,15] etc.).

4 Limitations

This LCIA examines the possibilities offered by secondary measures for reducing emissions, especially NO_x, from diesel engines in heavy-duty vehicles >14 t total weight. Other options which can achieve the same objectives (change in fuel properties, exhaust gas and optimization of engine fuel consumption) were also investigated extensively. The results of research projects extending over many years were included in the study for the range of heavy-duty vehicles under examination. This also holds for the change in diesel fuel properties. It must therefore be explicitly stated that the results of the present LCIA can be interpreted only in connection with an assurance of the validity of the achieved results for emissions reduction, applied traffic data, the model assumptions and model setup. A number of characterization and weighting methods were implemented to limit the limitations of the LCIA phase. These results also depend on the validity of the applied characterization and weighting models. With regard to the applied weighting models explicit reference is made to the current data gaps for evaluation of the LCI results. The data gaps for the characterization factors are also given in **Appendix 1** and the cited literature sources for the applied weighting models.

5 Conclusions

On the basis of the outcome of the mandatory elements (**Section 1.2**) and the determined category endpoints it was calculated that variant V_2 represents the best alternative for emissions reduction for all investigated impact categories. Variant V_3 takes second place with the exception of the impact categories for acidification and generation of photooxidants. In these two cases variant V_3 fell in the fourth and third places, respectively. Variant V_1 took second place for the impact categories for both acidification and generation of photooxidants. Normalization of the category indicator results for each measure scenario relative to the category indicator results for the reference year 1995 (**Section 2.1**) confirmed nearly all of the above results for the order of best alternatives. Only for the land use impact category did variant V_3 take first place. The picture was changed nearly completely by normalization of the category endpoints with respect to distance traveled with the corresponding measure (**Section 2.1**). Variant V_3 now took the best place for nearly all category indicator results. This result did not hold only for the impact categories for human toxicity, acidification and generation of photooxidants. For these impact categories variant V_2 held first place and variant V_3 took second place once (human toxicity) and third place twice. After the weighting step (**Section 2.2**) variant V_2 took the best place for all of the applied methods. Variant V_1 now held second place in the weighting results for nearly all methods. Only for the results calculated using the EPS method did variant V_3 take second place. As no perfectly clear ranking can be distinguished for evaluation of these results and no correlation can be established to the economical effects of the corresponding measures, the currently existing recommendations from ISO/DIS 14042 for this phase of the LCIA and the ISO/DIS 14043 (cf. [16]) evaluation to follow must be completed with further parameters. These results will be presented in a study to follow this publication.

Abbreviations and Symbols	
AK	Spent nuclear fuel in underground repositories,
AKW	Nuclear power plant,
Eq	Equivalent,
DBM	Dead biomass,
DIMB	Thick-walled metallic parts, rubble,
DÜMB	Thin-walled metallic parts, rubble,
ECU	European Currency Unit,
ELU	Environmental Load Units,
EU3M	Scenario for introduction of diesel engines of exhaust gas class EURO 3,
ExP	Exposed persons in nuclear power plant,
HC	Hydrocarbons,
K	Scenario for diesel fuel parameter change,
CQR	Concept of Quality target Relations ('molar method'),
MEA	Monoethanolamine,
MVA	Waste incineration plant,
n. c.	Not accounted for,
S	Sulfur,
SA	Products of fission and activation (not including tritium),
SCR	Selective catalytic reduction,
EPSU	Environmental Pollution Source Units,
SKW-DeNOx	SCR system for NO_x reduction from hard-coal fired power plants,
SMA	Weakly and moderately active solids in underground repositories,
SMVA	Non radioactive hazardous waste incineration plant,
SOA	Stratospheric ozone depletion,
SP	Sensitivity test,
PLC	Product life cycle,
EBP	Ecological burden points,
ERP	Ecological relief points,
$V_1 - V_4$	scenarios for introduction of exhaust-gas side measures (see [2]).

References

[1] DIN (1997): Environmental management – Life Cycle Assessment – Principles and framework (EN ISO 14040). Beuth, Berlin

[2] Bárzaga Castellanos L, Neufert R, Markert B (2001): Life Cycle Assessment for the Implementation of Emission Control Measures for the Freight Traffic with Heavy Duty Vehicles in Germany, Phase 1: Life Cycle Inventory Analysis. Int J LCA 6 (4) 231–242

[3] DIN (1999): Environmental management – Life Cycle Assessment – Life Cycle Impact Assessment (ISO/DIS 14042). Beuth, Berlin

[4] VDI (1995): Kumulierter Energieaufwand, Begriffe, Definitionen, Berechnungsmethoden (VDI 4600 Entwurf). Beuth, Berlin, Düsseldorf

[5] Lindfors LG et al. (1995): Nordic Guidelines on Life Cycle Assessment (Nord 1995:20). Nordic Council of Ministers, Copenhagen, Denmark

[6] von Bortel R (1997): Analyse ausgewählter Emissionen von Dieselmotoren in Abhängigkeit von der Kraftstoffzusammensetzung, Diss. Technische Universität Carolo-Wilhemina zu Braunschweig. Paper flyer, Clausthal-Zellerfeld

[7] Gebler W (1992): Ökobilanzen in der Abfallwirtschaft, 2nd revised edition. Erich Schmidt, Bielefeld

[8] Wehowsky P et al. (1994): Strom- und Wärmeerzeugende Anlagen auf fossiler und nuklearer Grundlage, IKARUS Report 4-06. Jülich Research Center, Jülich

[9] Braunschweig A, Müller-Wenk R (1993): Ökobilanzen für Unternehmungen: Eine Wegleitung für die Praxis. Paul Haupt, Bern, Stuttgart, Vienna

[10] Steen B, Ryding SO (1992): The EPS Enviro-Accounting Method. An application of environmental accounting principles for evaluation and valuation of environmental impact in product design. Swedish Environmental Research Institute (IVL, IVL Report No. B 1080), Göteborg, Sweden

[11] Braunschweig A, Förster R, Hofstetter P, Müller-Wenk R (1994): Evaluation und Weiterentwicklung von Bewertungsmethoden für Ökobilanzen – Erste Ergebnisse, IWÖ Discussion Contribution No. 19. Institut für Wirtschaft und Ökologie, St. Gallen

[12] Böring JA (1994): Methoden betrieblicher Ökobilanzierung, Diss. Universität Augsburg, Hochschulschriften Volume 16. Metropolis, Marburg

[13] Deutscher Bundestag, Enquete-Kommission zum Schutz des Menschen und der Umwelt (Hrsg) (1995): Studienprogramm Umweltverträgliches Stoffstrommanagement, Volume 1, Konzepte. Economica, Bonn

[14] Fasold, H. G.; Freitag, F.; Heymer, D. and van Heyden, L. (1994): Erdgastransport, -speicherung und -verteilung, IKARUS Report 4-14. Jülich Research Center, Jülich

[15] Hedden K, Jess A (1994): Bereich Raffinerien und Ölveredelung, IKARUS Report 4-04. Jülich Research Center, Jülich

[16] DIN (1999): Environmental management – Life Cycle Assessment – Life cycle interpretation (ISO/DIS 14043), Beuth, Berlin

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Appendix 1: Result of the classification, applied characterization factors and influence of the different results of the Life Cycle Inventory Analysis on the category endpoints according to the applied characterization factors

Impact category	Factor	Unit	Actual, 1995	K, 2010	K+EU3 M, 2010	V_1, 2010	V_2, 2010	V_3, 2010	V_4, 2010	V_2, SP, 2010	V_3, SP, 2010
Influence			%	%	%	%	%	%	%	%	%
1. Resources											
Energy consumption											
Thermal energy MJ	3.6	kWh/MJ	99.37	99.37	99.37	96.05	99.66	99.56	99.37	99.66	99.56
Current, refinery, kWh	1	kWh/kWh	0.20	0.20	0.20	0.00	0.22	0.21	0.20	0.22	0.21
Current, Germany network kWh	1	kWh/kWh	0.43	0.43	0.43	3.95	0.12	0.23	0.43	0.12	0.23
Total			100	100	100	100	100	100	100	100	100
Material consumption											
Raw oil used t	25	t^{-1}	94.25	94.25	94.25	0.00	94.04	94.13	94.25	94.04	94.13
Fuel mix Germany (fossil) kg	0.026	kg^{-1}	5.75	5.75	5.75	0.00	5.74	5.75	5.75	5.74	5.75
Nuclear fuel kg	0.0172	kg^{-1}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO_2 kg	0.0142	kg^{-1}	0.00	0.00	0.00	39.23	0.07	0.04	0.00	0.07	0.04
WO_3 kg	0.0182	kg^{-1}	0.00	0.00	0.00	4.53	0.05	0.02	0.00	0.05	0.02
V_2O_5 kg	0.074	kg^{-1}	0.00	0.00	0.00	2.97	0.01	0.00	0.00	0.01	0.00
FeS_2 kg	0.0084	kg^{-1}	0.00	0.00	0.00	53.27	0.09	0.06	0.00	0.09	0.06
Total			100	100	100	100	100	100	100	100	100
2. Water consumption											
SKW-DeNOx g	1	g/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Process water g	1	g/g	4.35	4.35	4.35	73.33	4.45	4.42	4.35	4.45	4.42
H_2O steam g	1	g/g	1.84	1.84	1.84	0.00	1.83	1.83	1.84	1.83	1.83
Cooling water g	1	g/g	93.81	93.81	93.81	0.00	93.67	93.72	93.81	93.67	93.72
Cleaning water g	1	g/g	0.00	0.00	0.00	21.27	0.03	0.02	0.00	0.03	0.02
Drinking water g	1	g/g	0.00	0.00	0.00	5.40	0.01	0.01	0.00	0.01	0.01
Total			100	100	100	100	100	100	100	100	100
3. Land use											
Land use m^2	0.0871	ELU/m^2	100	100	100	100	100	100	100	100	100
Total			100	100	100	100	100	100	100	100	100
4. Human toxicity											
CO g	$2*10^{-5}$	g body weight/g	0.56	0.70	-17.05	-0.03	0.10	0.49	1.12	0.10	0.49
Particulate matter g	0.017	g body weight/g	99.44	99.30	117.05	100.03	99.90	99.51	98.88	99.90	99.51
Total			100	100	100	100	100	100	100	100	100
5. Glass house effect											
CO_2 g	1	g CO_2-Eq/g	99.85	99.93	99.12	53.32	101.01	100.39	101.94	101.01	100.39
CO_2-Eq g	1	g CO_2-Eq/g	0.00	0.00	0.00	36.20	-0.82	-0.56	0.00	-0.82	-0.56
N_2O g	320	g CO_2-Eq/g	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02	0.02
CH_4 g	24.5	g CO_2-Eq/g	0.13	0.05	0.86	10.48	-0.20	0.16	-1.96	-0.20	0.16
Total			100	100	100	100	100	100	100	100	100

Impact category	Factor	Unit	Actual, 1995	K, 2010	K+EU3 M, 2010	V_1, 2010	V_2, 2010	V_3, 2010	V_4, 2010	V_2, SP, 2010	V_3, SP, 2010
Influence			%	%	%	%	%	%	%	%	%
6. SOA	**none**	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.
7. Acidification											
SO_2 g	1	g SO_2-Eq/g	11.30	8.63	-1.27	-0.07	1.20	3.51	7.08	1.41	4.13
HCl g	0.88	g SO_2-Eq/g	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01
NO_2 g	0.7	g SO_2-Eq/g	88.69	91.36	101.28	101.43	100.35	99.61	92.92	100.41	99.54
NH_3 [mg]	0.0019	g SO_2-Eq/g	0.00	0.00	0.00	-1.36	-1.55	-3.12	0.00	-1.83	-3.67
Total			100	100	100	100	100	100	100	100	100
8. Eutrophication:											
Nitrate g	0.1	g PO_4-Eq/g	0.00	0.00	0.00	9.44	-1.28	-0.82	0.00	-1.28	-0.82
Ammonium g	0.33	g PO_4-Eq/g	34.33	34.33	34.33	82.32	27.54	29.98	34.33	27.54	29.98
Phosphate g	1	g PO_4-Eq/g	0.00	0.00	0.00	7.82	-1.06	-0.68	0.00	-1.06	-0.68
Chemical Oxygen Demand, COD g	0.022	g PO_4-Eq/g	55.30	55.30	55.30	0.43	62.99	60.21	55.30	62.99	60.21
Biological Oxygen Demand, BOD g	0.022	g PO_4-Eq/g	10.37	10.37	10.37	0.00	11.82	11.30	10.37	11.82	11.30
Total			100	100	100	100	100	100	100	100	100
9. Summer smog											
NO_2 g	1.04	g Ozone/g	63.76	89.66	614.62	93.99	93.61	50.71	30.39	93.26	49.28
NMVOC g	5.01	g Ozone/g	36.24	10.34	-514.62	6.01	6.39	49.29	69.61	6.74	50.72
Total			100	100	100	100	100	100	100	100	100
10. Ecotoxicity											
H_2S g	0.12	t DBM/g	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
HCN g	9.51	t DBM/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEA g	**none**	t DBM/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dust g	0.0043	t DBM/g	0.05	0.13	0.04	-0.10	0.02	0.03	-0.01	0.02	0.03
HF g	1.0	t DBM/g	0.04	0.11	0.04	0.00	0.03	0.04	0.00	0.03	0.04
Sulfate g	0.001	t DBM/g	0.00	0.01	0.00	-1.09	-0.21	-0.14	0.00	-0.21	-0.14
Chloride g	0.001	t DBM/g	0.07	0.18	0.06	-0.10	0.03	0.04	-0.01	0.03	0.04
Zinc g	0.01	t DBM/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Titanium g	0.001	t DBM/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium g	1.0	t DBM/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tungsten g	0.01	t DBM/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron g	0.01	t DBM/g	0.00	0.00	0.00	-5.54	-1.06	-0.74	0.00	-1.06	-0.74
Oil content g	**none**	t DBM/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitated materials g	**none**	t DBM/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aromatic hydrocarbons g	116.36	t DBM/g	16.30	43.66	14.83	-3.12	12.28	13.17	-1.79	12.28	13.17

Impact category	Factor	Unit	Actual, 1995	K, 2010	K+EU3 M, 2010	V_1, 2010	V_2, 2010	V_3, 2010	V_4, 2010	V_2, SP, 2010	V_3, SP, 2010
Influence			%	%	%	%	%	%	%	%	%
Sodium g	none	t DBM/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
In addition:											
CO g	0.0136	t DBM/g	33.10	25.13	90.39	-4.60	8.89	31.87	57.76	8.89	31.87
Particulate matter g	0.1	t DBM/g	50.44	30.77	-5.37	114.56	80.02	55.75	44.04	80.02	55.75
Total			100	100	100	100	100	100	100	100	100
11. Radiation											
Noble gases Bq	1	-	20.04	20.04	20.04	0	20.04	20.04	20.04	20.04	20.04
Long-life aerosols Bq	1	-	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
Tritium Bq	1	-	2.40	2.40	2.40	0	2.40	2.40	2.40	2.40	2.40
Iodine 131 Bq	1	-	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
SA Bq	1	-	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
Tritium Bq	1	-	23.24	23.24	23.24	0	23.24	23.24	23.24	23.24	23.24
Ball resins Bq	1	-	26.68	26.68	26.68	0	26.68	26.68	26.68	26.68	26.68
Filter cartridge applications Bq	1	-	2.67	2.67	2.67	0	2.67	2.67	2.67	2.67	2.67
DIMB Bq	1	-	2.67	2.67	2.67	0	2.67	2.67	2.67	2.67	2.67
Evaporation concentrate Bq	1	-	16.01	16.01	16.01	0	16.01	16.01	16.01	16.01	16.01
DŬMB Bq	1	-	3.74	3.74	3.74	0	3.74	3.74	3.74	3.74	3.74
Sludge Bq	1	-	2.43	2.43	2.43	0	2.43	2.43	2.43	2.43	2.43
Paper, textiles, plastics Bq	1	-	0.13	0.13	0.13	0	0.13	0.13	0.13	0.13	0.13
Oils Bq	1	-	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
Total			100	100	100	0	100	100	100	100	100
ExP Man-Sievert/a	1	-	100	100	100	0	100	100	100	100	100
Total			100	100	100	0	100	100	100	100	100
12. Noise	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.	n. c.
13. Waste											
S g	0.0	EBP/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gypsum g	0.0	EBP/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Recycling g	0.0	EBP/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Recovery g	0.0	EBP/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inert material dump g	0.0	EBP/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residual material dump g	0.22	EBP/g	3.65	3.65	3.65	36.08	2.26	2.72	3.65	2.26	2.72
Ash g	0.22	EBP/g	88.55	88.55	88.55	0.00	92.22	90.98	88.55	92.22	90.98
Reactor dump g	0.22	EBP/g	0.12	0.12	0.12	4.78	-0.07	-0.01	0.12	-0.07	-0.01
Land farming g	0.22	EBP/g	1.54	1.54	1.54	11.28	1.10	1.24	1.54	1.10	1.24
Boiling waste to MVA g	0.13	EBP/g	0.03	0.03	0.03	41.27	-1.61	-1.05	0.03	-1.61	-1.05
Special waste to SMVA g	0.21	EBP/g	0.99	0.99	0.99	6.58	0.76	0.84	0.99	0.76	0.84
Special waste to mine dump kg	100000	EBP/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AK kg	100000	EBP/kg	1.68	1.68	1.68	0.00	1.75	1.72	1.68	1.75	1.72
SMA kg	100000	EBP/kg	3.45	3.45	3.45	0.00	3.59	3.54	3.45	3.59	3.54
Total :			100	100	100	100	100	100	100	100	100